HYPERFINE FIELD STUDIES IN METALS AND ALLOYS

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In the year under review, (a) we have continued the measurements of the hyperfine magnetic fields (hmf), their temperature dependence and their sign, at ^{111}Cd probes and ^{99}Ru probes in Heusler alloys; (b) the hmf measurements in chromium-based chalcogenide spinels have been made at ^{111}Cd probes and the studies have now been extended to ^{99}Ru and ^{119}Sn probes; (c) we have made some preliminary studies of the hyperfine magnetic field in the spin glass state of CuWn and AgMn with ^{111}Cd probes and the preliminary TDPAC studies on $ErRh_4B_4$ have been started; (d) lastly, we have been successful in measuring the quadrupole interaction energies at ^{111}Cd in Cd, In, Zn and Sb metals, at ^{100}Rh in Zn and Sb metals and at ^{99}Ru in Sb metal.

a) The hmf studies by TDPAC. The technique has been described in earlier reports. Such studies are usually made with chemically separated, carrier-free isotopes which are electroplated onto the alloy constituents before melting them together. We make ^{111}In by Ag(α,xn), Cd(p,xn) and In(p,xn) reactions. The alloys are made with a milligram or two of the bombarded target material. Natural Cd targets bombarded with less than 40 MeV protons and natural In targets bombarded with about 60 MeV protons yield ^{111}In practically free from interfering radiations. The use of such target materials has made possible TDPAC studies with the 175 keV-247 keV γ-γ cascade lasting for as long as 4 weeks without large random coincidences. The hmf data on Heusler alloys are given in Table 1. The last three columns in this table give the hmf and its sign (where available) at the probe mentioned at X, Mn and Y sites in Heusler alloys X_2Mn Y and X Mn Y. The values are for the temperature 0°K. These data are based on TDPAC, Mossbauer and nmr experiments. The significance of these results can be appreciated by noticing that the hmf at Cd, In, Sn and Sb probes in Fe and Ni are large and negative for Cd, they become smaller in magnitude as one moves to higher atomic number of the s-p elements. The hmf changes sign at Sn probe. This general trend seems to hold for Ni and Cu based Heusler alloys as shown in Figs. 1a) and 1b). The hmf seen by a probe seems to depend sensitively on the ionic charge of the probe. It seems to depend also on the atoms that surround the probe.

b) Measurements of hmf in chalcogenide spinels. In pursuing the studies of hmf in the chromium-based chalcogenide spinels, we have recently measured the hmf at ^{99}Ru in Cu Cr Rh Te_4 and at ^{111}Cd in $CuCr_2Se_4$ and at ^{119}Sn in Cu $Cr_{1.9}Sn_{.1}Te_4$.

c) Studies of hmf in spin glass. Noble metals with a small concentration of 3d elements (Cu Mn, Ag Mn, Au Fe) show a cusp in AC susceptibility at a freezing

temperature, which is concentration dependent. It is believed that the spins of the magnetic ions become randomly frozen. There is a controversy as to whether there is a phase transition to a spin glass state at a fixed T_F or whether the T_F is frequency dependent. Mossbauer experiments show a unique hmf, but the T_F with ^{119}Sn is somewhat larger than what is found in experiments with ^{57}Fe. Muon spin rotation studies have shown a steep rise in the spin relaxation rate with temperature above T_F. TDPAC has possibilities of measuring hmf and T_f with microscopic probes at substitutional sites over a wide frequency range. We

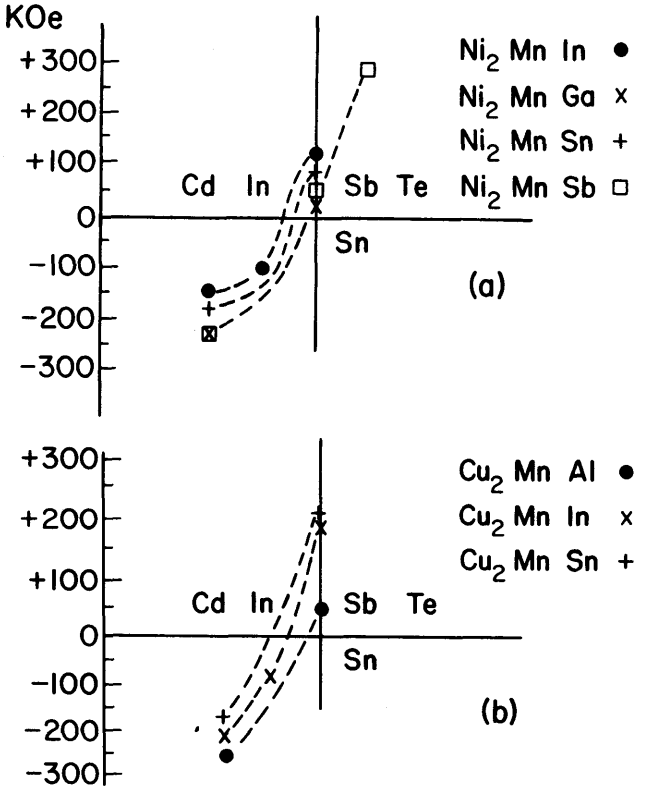

Figure 1.

have performed some preliminary experiments with AgMn and CuMn, where we have used ^{111}In as a probe and measured the Larmor oscillation period in the spin glass state at 1.5°K. The TDPAC spectra are shown in Figs. 2 a), b) and c). In our studies with ^{99}Rh in $ErRh_4B_4$, we have bombarded a sample of $ErRh_4B_4$ with

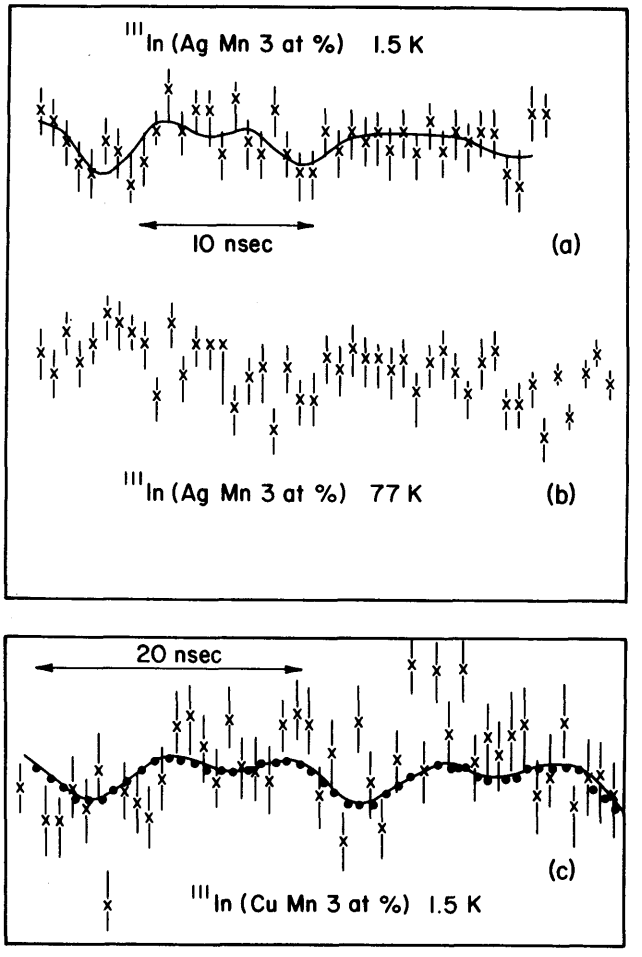

Figure 2.

protons of 43 MeV and produced a clean source of ^{99}Rh. With this source we have measured the lifetime of the 85 keV state in ^{100}Rh with a true to random ratio of better than 50:1; the radiations of Tm isotopes cause no interference for 3 weeks. The TDPAC studies at liquid helium temperatures are being planned.

d) Measurements of quadrupole interaction frequency ν_Q: We have measured by TDPAC techniques the quadrupole interaction frequency ν_Q of ^{111}Cd in Cd, In, Zn and Sb metals, of ^{99}Ru in Sb metal and of ^{100}Rh in Zn and Sb

metals. A milligram or two (less than 0.5 %) of the Cd and In metal targets containing ^{111}In activity, and of Rh metal target containing both ^{99}Rh and ^{100}Pd activities, are alloyed in the metal of interest. The TDPAC spectra are taken with two detectors at 180°. The spectra are represented by

$$W(180°,t) = e^{-t/\tau}[1 + A_2G_2(t)P_2(\cos\theta)]$$

When the perturbation is caused by quadrupole interaction, $G_2(t)$ depends on the spin of the intermediate state, which for ^{99}Ru is 3/2, for ^{111}In is 5/2, and for ^{100}Rh is 2. For I=3/2,

$G_2(t) = (1/5)[1 + 4\cos\omega t]$

For I = 5/2,

$G_2(t) = (1/5)[13/7)\cos\omega t + (10/7)\cos2\omega t + (5/7)\cos3\omega t]$

and for I = 2,

$G_2(t) = (1/5)[13/7 + (2/7)\cos\omega t + (12/7)\cos3\omega t + (8/7)\cos4\omega t]$

In Fig. 3, the TDPAC spectra of ^{100}Pd in Zn metal and Sb metal at 293°K are given; for the Zn case, the value of the period is 700 nsec corresponding to the ν_Q-value of 11.4 MHz; for the Sb case, which has been studied for the first time, the period is 1200 nsec and the ν_Q is 6.7 MHz.

Table 1. Measurements of the Hyperfine Fields.

X Mn Y	Lattice Const. (A°)	Magnetic Moment (μB)	T_c (°K)	Hyperfine Fields (kOe) H(X)	H(Mn)	H(Y)
Ni_2Mn Ga	5.825	4.17	379	Ni±125	-297	Ga -29
				Ru 178		Cd -228±3
						Sn 20
Ni_2Mn In	6.07	4.4	323	Ni 141	-302	Cd -160±1
						In -112
						Sn 109
Ni_2Mn Sn	6.052	4.05	344	Ni -123	313	Cd 181±2
						Sn +87
Ni_2Mn Sb	6.00	3.27	360	Ni -60	285	Cd 225±3
						Sn +52
						Sb 293
Cu_2 Mn Al	5.949	4.12	630	Cu -214	-214	Al 60
						-35
						Cd 250±5
						Sn 50
Cu_2Mn In	6.20	3.95	500	Cu -200	-214	Cd 217±1
						In -93.2
						Sn +196
Cu_2Mn Sn	6.173	4.11	530	Cu -175	-231	Cd 167±3
						Sn + 200
Rh_2Mn Ge	6.030	4.30	450	Ru 195±11	Mn	Cd 189±6
						Sn 50

X Mn Y	Lattice Const. (A°)	Magnetic Moment (μB)	T_c (°K)	Hyperfine Fields (kOe) H(X)	H(Mn)	H(Y)
Rh_2Mn Sn	6.252	3.10	412	Ru -185	360	Cd 190±5
						Sn +25.5
Ph_2Mn Pb	6.332	4.12	355	Ru 280	Mn 394	Cd 144±2
						Sn +25
Rh_2Mn Sb 1.12 .88			348k	Rh -216	-389	Cd Sn -43 Sb
Pd_2Mn Ge	6.174	3.2	260	Pd		Cd 247±4
Pd_2Mn Sn	6.38	4.23	189	Pd-266	350	Cd -205
						Sn -35
Pd_2Mn Sb	6.424	4.4	247	300±100	347	Cd -206±5
						Sn +210
						Sb 579
						Te 860
						I 507
Au_2Mn Al			140	Au 1540	-352	Al 32
Au_2Mn In						Cd 155±3(77k)
Ni Mn Sb	5.913	3.8	720			
						Cd -214±1
						Sb +292
Ru Mn Ga						
Rh Mn Sb	6.152	3.36	320			Sb 116
Pd Mn Sb	6.246	395	500			
						Sn 103±b
						Sb 330
						Te 572
						I 681
Ir Mn Sn	6.128	2.25	265	Ir -650		Sn 28
Ir Mn Sb	6.164	3.1	290			Cd 169 (77k)
Pt Mn Ga	6.15	3.18	220			±5
Pt Mn Sn	6.269	3.54	330	Pt -800	332	Cd +95
				Au -705		Sn -60
Pt Mn Sb	6.195	4.02	575			Cd+166±4
						Sb +225